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Adaptive Sampling Approach to Environmental Site Characterization: Phase I Demonstration

Robert J. Floran, Grace E. Bujewski, Robert L. Johnson

Prepared by
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A technology demonstration that optimizes sampling strategies and real-time data collection was carried out at the Kirtland Air Force Base RB-11 Radioactive Burial Site, Albuquerque, New Mexico in August 1994. The project, which was funded by the Strategic Environmental Research and Development Program (SERDP), involved the application of a geostatistical-based Adaptive Sampling methodology and software with on-site field screening of soils for radiation, organic compounds and metals. The software, known as Plume™, was developed at Argonne National Laboratory as part of the DOE/OTD-funded Mixed Waste Landfill Integrated Demonstration (MWLID).

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Adaptive Sampling Approach to Environmental Site Characterization: Phase I Demonstration

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ABSTRACT

A technology demonstration that optimizes sampling strategies and real-time data collection was carried out at the Kirtland Air Force Base (KAFB) RB-11 Radioactive Burial Site, Albuquerque, New Mexico in August 1994. The project, which was funded by the Strategic Environmental Research and Development Program (SERDP), involved the application of a geostatistical-based Adaptive Sampling methodology and software with on-site field screening of soils for radiation, organic compounds and metals. The software, known as Plume™, was developed at Argonne National Laboratory as part of the DOE/OTD-funded Mixed Waste Landfill Integrated Demonstration (MWLID).

The objective of the investigation was to compare an innovative Adaptive Sampling approach that stressed real-time decision-making with a conventional RCRA-driven site characterization carried out by the Air Force. The latter investigation used a standard drilling and sampling plan as mandated by the Environmental Protection Agency (EPA). To make the comparison realistic, the same contractors and sampling equipment (Geoprobe® soil samplers) were used. In both investigations, soil samples were collected at several depths at numerous locations adjacent to burial trenches that contain low-level radioactive waste and animal carcasses; some trenches may also contain mixed waste. Neither study revealed the presence of contaminants appreciably above risk based action levels, indicating that minimal to no migration has occurred away from the trenches. The combination of Adaptive Sampling with field screening achieved a similar level of confidence compared to the Resource Conservation and Recovery Act (RCRA) investigation regarding the potential migration of contaminants at the site. By comparison, the RCRA investigation regarding the potential migration of contaminants at the site. By comparison, the Adaptive Sampling program drilled 28 locations (vs. 36 for the conventional investigation), collected 81

samples (vs. 163), and sent 15 samples (vs. 163) off-site for laboratory analysis. In addition, the field work took 3 1/2 days compared to 13 days for the RCRA investigation. These figures translate into large cost savings because 22% fewer boreholes were drilled, 50% fewer samples were collected, and 91% fewer samples were analyzed off-site. Of these costs, the most significant savings involved laboratory analyses which typically cost greater than \$1K per sample. Additional costs associated with the increased level of field screening carried out and costs associated with the use of the Adaptive Sampling software are relatively minor compared to the savings achieved.

During the field demonstration, a SunSPARC workstation containing the geostatistical program was successfully linked via the Internet with an identical workstation at Argonne. In the near future, it will be possible to support real-time sampling decisions in the field from remote locations thousands of miles away.

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This work was funded by the Strategic Environmental Research and Development Program (SERDP) and the U.S. Army Corps of Engineers under the Military Interdepartmental Purchase Request Number E8794L054/SNL2, a joint DOD/DOE/EPA initiative to develop and demonstrate innovative methods for environmental site cleanup. We would also like to acknowledge the Mixed Waste Landfill Integrated Demonstration (MWLID) project, which is funded through DOE's Office of Technology Development (OTD). The MWLID demonstration at the KAFB RB-11 site in 1993 and previous funding of Plume™ development at Argonne National Laboratory provided the technical foundation and inspiration for the work carried out under SERDP. We would like to thank the Environmental Management Division of Kirtland Air Force Base, New Mexico, under the direction of Col. Thomas A. Norris, for their cooperation and their support.

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ACRONYMS

DOE	Department of Energy
EPA	Environmental Protection Agency
ft	feet
FTP	file transfer protocol
G-M	Geiger-Muller
HHRB	human health risk based
KAFB	Kirtland Air Force Base
m	meter
MWLID	Mixed Waste Landfill Integrated Demonstration
OTD	Office of Technology Development
PID	photoionization detector
ppm	parts per million
QA	Quality Assurance
QC	Quality Control
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
SERDP	Strategic Environmental Research and Development Program
SNL	Sandia National Laboratories
SVOCs	semi-volatile organic compounds
TAL	Target Analyte List
VOCs	volatile organic compounds
XRF	x-ray fluorescence
yrs	years

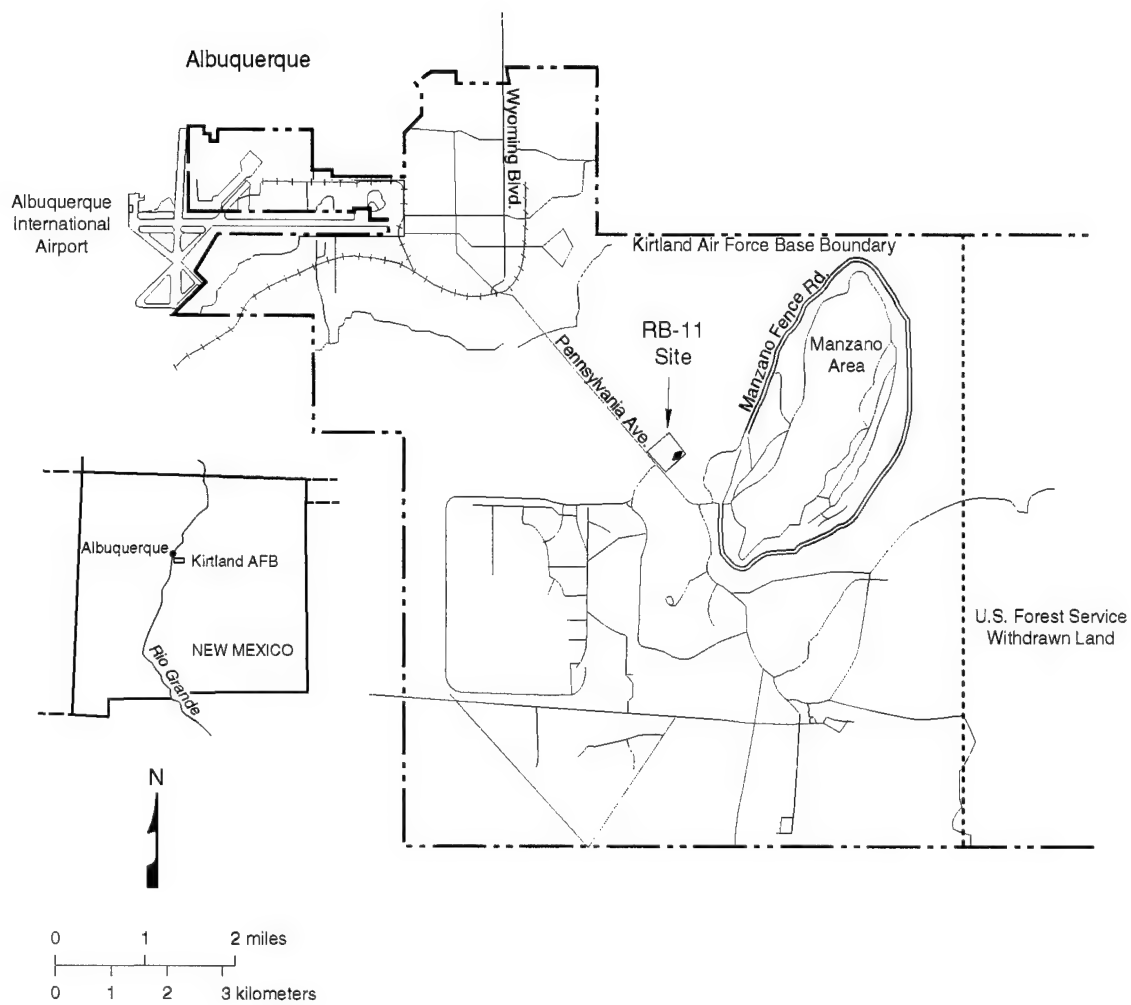
INTRODUCTION

The Kirtland Air Force Base RB-11 radioactive waste site, located in Bernalillo County, southeast of Albuquerque (Figure 1), is a 0.02 sq. km. (4.5 acre) landfill containing nine or ten disposal trenches (the exact number is unknown). Incomplete records suggest that the four earliest trenches located at the southern end of the site (Figure 2) are 15 m (~50 ft.) long by 3 m (~9 ft.) deep by 0.6 m (2 ft.) wide and have about 1.2 m (4 ft.) of earth cover. Two of these trenches are covered with asphalt. The remaining trenches are described as being 30 m long (~100 ft.), 6-7 m (20-24 ft.) deep and 2 m (6 ft.) wide with 1.2 m (4 ft.) of earth cover.

The KAFB RB-11 landfill was used to dispose of laboratory wastes (gloves, wipes, etc.) and animal carcasses that had received varying exposure doses of radiation as a result of military research activities carried out in the 1960s and early 1970s. Most of the radioactivity was in the form of induced activity and short-lived radionuclides. However, based on interviews with former employees who worked at the site, it is likely that several millicuries of radionuclides with longer half-lives are present, e.g., ^{137}Cs ($t_{1/2}=30$ yrs), ^{90}Sr ($t_{1/2}=28$ yrs). Only a small portion of the waste appears to have been buried in drums. In addition to the radioactive wastes, an undetermined amount of hazardous and toxic liquid wastes may also have been disposed of in the trenches. These included small amounts of acids, mercury, cyanides and silver.

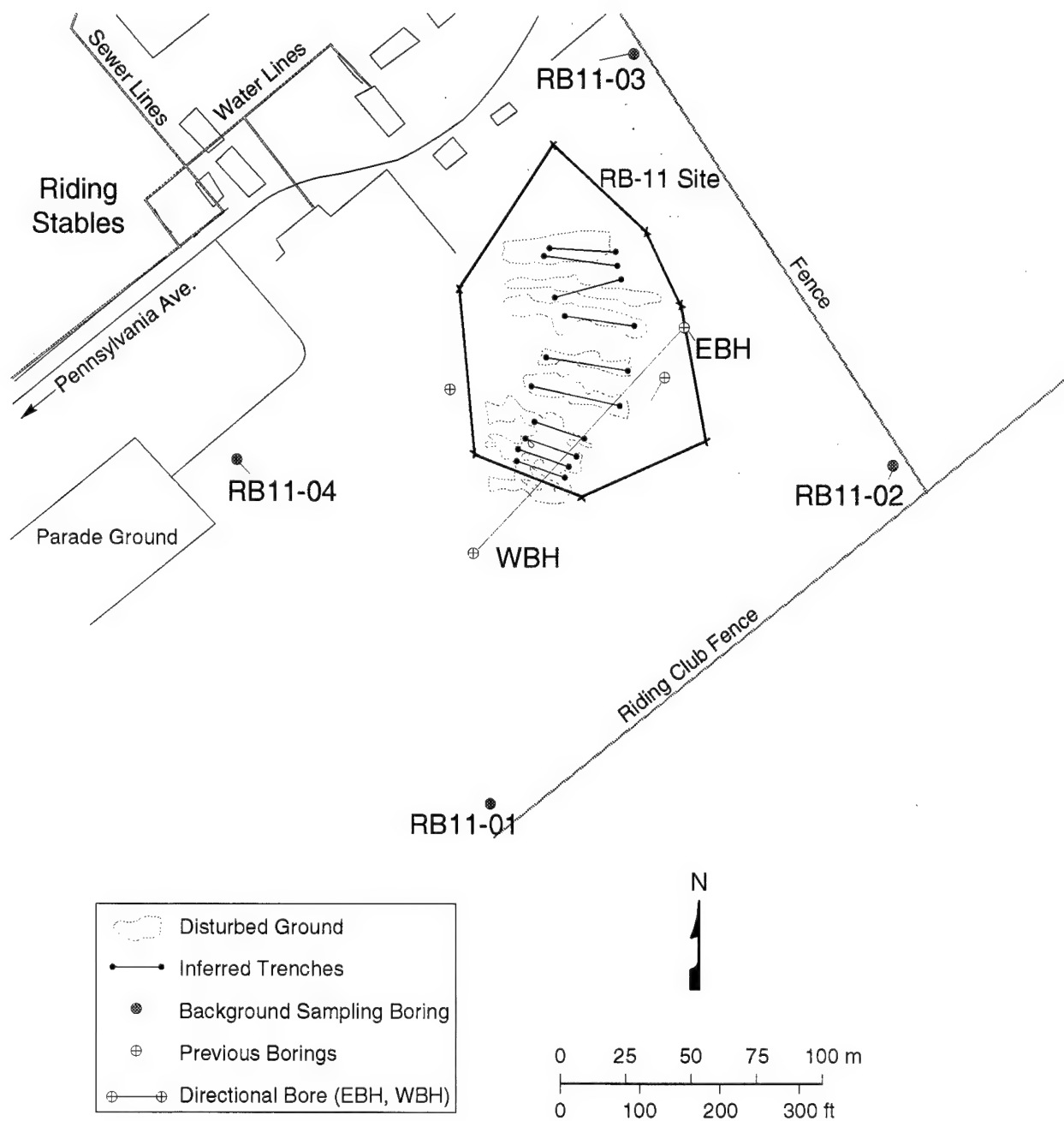
The purpose of this paper is to describe a case study in which traditional site characterization methods currently approved by Environmental Protection Agency (EPA), such as grid drilling and off-site laboratory analysis, are compared with an innovative approach that combines sample optimization with real-time field screening. The innovative approach achieves similar results but is considerably more cost-effective and time-efficient because fewer boreholes need to be drilled and fewer samples need be collected and analyzed off-site. In addition, the sample optimization strategy employed allows real-time decisions to be made in the field regarding additional sampling, thus obviating the need for more costly supplemental sampling programs during a revisit of the site.

Our aim is to present an alternative site characterization methodology that is equivalent to meeting the information needs of a regulatory-driven program, while being more efficient than traditional methods. We consider the present study to be a first step in demonstrating this new approach. Further, similar investigations will be necessary to demonstrate that data quality objectives Quality Assurance/Quality Control (QA/QC), statistical validity, and regulatory satisfaction can be achieved at a broader spectrum of sites.



TRI-6621-118-0

Figure 1. Location of RB-11 Mixed Waste Landfill, Kirtland Air Force Base, New Mexico.



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Figure 2. RB-11 Site showing infrastructure, inferred location of waste trenches and surrounding disturbed ground. Background sampling points are shown at perimeter (RB11-1 through RB11-4).

PREVIOUS STUDIES: KAFB RCRA INVESTIGATION

The U.S. Air Force is responsible for implementing a final remediation action for the RB-11 site as required by the RCRA and under the Air Force Installation Restoration Program. Previous investigative activities at the RB-11 site are summarized in an EPA-approved Stage 2B Work Plan for Kirtland Air Force Base, New Mexico (U.S. Geological Survey, 1993). In addition, the KAFB RB-11 site was the focus of a minimally intrusive field demonstration of innovative site characterization technologies carried out by Sandia National Laboratories (SNL) in 1993 (Floran, 1994). None of these previous investigations conclusively identified any type of contamination at the site.

In July 1994, the Air Force Environmental Management Division and their contractor, Halliburton NUS, conducted a RCRA Facility Investigation (RFI) at KAFB RB-11 to fulfill requirements of their Part B Permit. The results of that investigation (Halliburton NUS - Draft, 1994) are briefly summarized here.

Conventional geophysical surveys including ground penetrating radar and EM-31/61 electromagnetic surveys were used in the RCRA investigation to define nine irregular trench areas, called "disturbed areas". These data were also used to choose locations for subsurface soil sampling, which was subsequently carried out with a Geoprobe® soil sampler. The objective of the sampling was to define the extent of contaminant migration, if any, away from the disturbed areas. As required by the Air Force, sampling locations were carefully chosen so that they were outside of the disturbed zones to prevent penetration of contaminant sources within the trenches.

After initial field screening, each soil sample was analyzed in an off-site laboratory for gross alpha and beta radiation; ^{226}Ra and ^{228}Ra ; volatile organic compounds (VOCs); semi-volatile organic compounds (SVOCs); cyanide; metals (including mercury); and petroleum hydrocarbons. The RCRA investigation concluded that there has been no significant migration of contaminants (organics, metals, radiation) away from the trenches. However, if a release not detected by field screening had been identified, the Air Force was prepared to revisit the site and conduct a detailed follow-up sampling program.

Over a span of 13 days, 36 boreholes were drilled and 163 soil samples were collected and sent to an off-site laboratory for analysis. These numbers do not include surface soil samples collected, additional drilling and sampling carried out for the EPA, and QA/QC samples that were required by RCRA (duplicates and blanks). If the latter activities were eliminated the total operation would have probably taken about 11 days. It should be noted that the Stage 2D-1 RFI report revealed that radiation levels averaged slightly above background adjacent to one trench, although the data were insufficient to verify that radiological migration has taken place (Halliburton NUS - Draft, 1994). In addition, trace amounts of mercury were detected in soil samples near three trenches, suggesting that limited migration of this metal may have occurred at the site.

ADAPTIVE SAMPLING INVESTIGATION

The Adaptive Sampling field demonstration took place during the first week in August 1994, approximately a week after completion of the RCRA investigation. The primary objective was to demonstrate that an Adaptive Sampling methodology that combines real-time field screening results with sample optimization could do an equivalent or better site characterization than could be achieved by using a conventional approach. The traditional type of site characterization often involves grid sampling, a heavy reliance on costly off-site analyses, and multiple site visits and sampling programs. To accomplish this objective, the Adaptive Sampling plan was compared with the conventional work plan carried out by the Air Force. To make the comparison as realistic as possible, the same drilling contractors, Halliburton NUS, and the same sampling equipment, Geoprobe®, were used in both investigations. Off-site laboratory analyses closely matched those specified in the KAFB Work Plan. The main objective of the analytical work performed during the investigation was to provide data that could be reliably compared with similar data obtained by the Air Force RCRA investigation.

There were significant differences in the way the two efforts were carried out. The Air Force followed the required conventional approach of collecting soil samples, conducting field screening (for organics and radiation only), and sending each sample to an off-site contract laboratory for confirmatory analysis as required by EPA in the RFI Work Plan. The RCRA investigation resulted in a four to six-week delay between collection of samples and obtaining analytical results. This time gap was potentially crucial because if any of the samples were found to be contaminated, an expensive follow-up investigation involving a new phase of sampling would have had to be conducted. Although both investigations employed field screening methods, the Adaptive Sampling strategy planned to use these results to obtain additional samples *immediately* if contamination were encountered, thus saving the added costs of revisiting the site.

A second major difference between the two investigations involved the number of samples collected. The modified RFI Work Plan, which addressed all EPA requirements, called for sampling every 5 feet to the bottom of each trench and also 10 feet below each trench. If contamination was encountered, sampling would continue every 3 m (10 ft.) until no further contamination was detected. A site characterization can be performed quicker and with fewer samples compared to a conventional RCRA characterization, yet achieve a similar level of confidence regarding potential migration of contaminants, by using Plume™, a geostatistical-based computer program.

APPLICATION OF THE ADAPTIVE SAMPLING METHODOLOGY

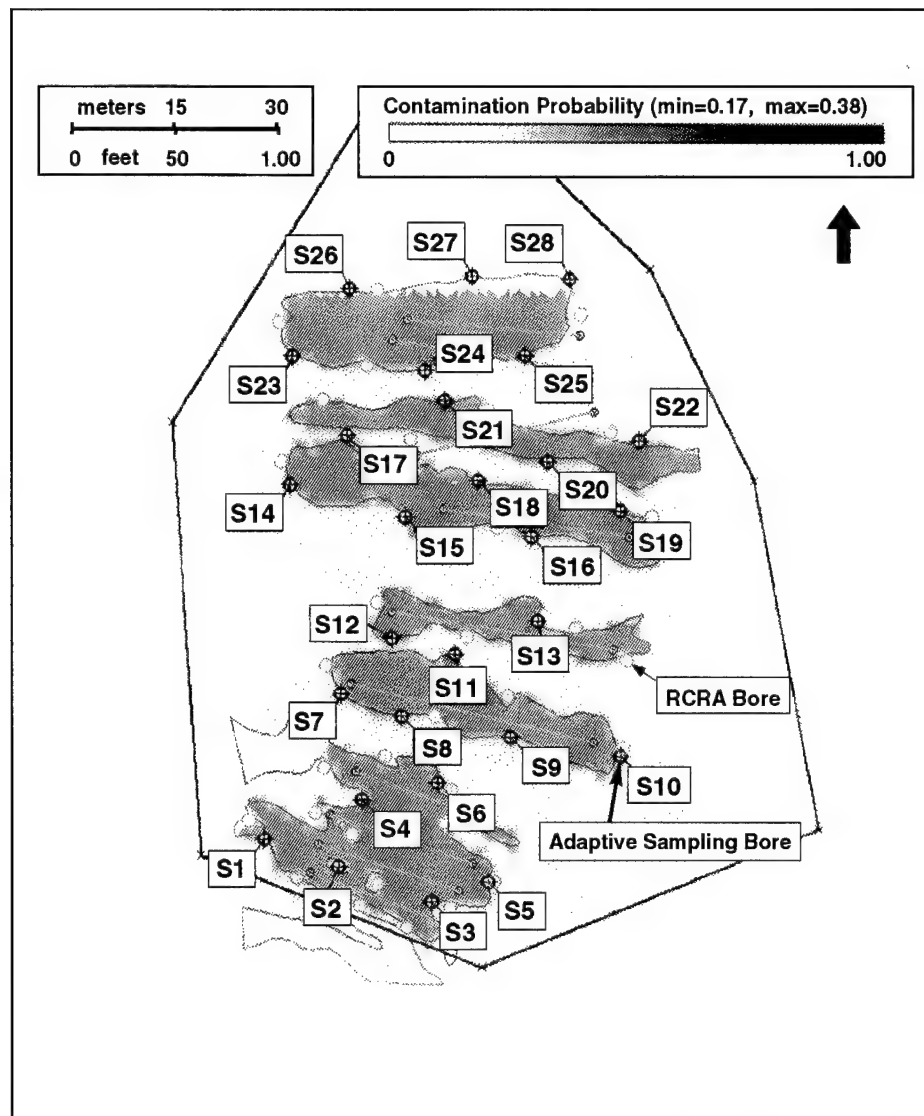
Plume™, a geostatistical-based computer program, and the Adaptive Sampling strategy were used to optimize drilling and sampling locations. Plume™ was developed at Argonne National Laboratory and is a module of SitePlanner™, a data management and display program marketed by Consolve, Inc. It is currently used by many government laboratories and private industry. Twenty-eight borehole locations were sited adjacent to the disposal trenches using Plume™. Sampling locations were numbered sequentially from roughly south to north beginning with S1 at the southwest and ending with S28 at the northeast (Figure 3). None of the bores drilled directly into the disturbed areas, which was also the case with the conventional RCRA investigation.

Plume™ combines Bayesian analysis with geostatistics to assist in the location of sampling points. A more complete description of Plume's™ methodology can be found in Johnson, 1993. Bayesian analysis allows a quantitative merging of "soft" information for a site with hard sampling data. Soft information can include historical records, aerial photographs, non-intrusive geophysical survey results, etc. This kind of information is used to form an initial conceptual image regarding the probable location and extent of contamination. Plume™ uses indicator geostatistics to update and refine the conceptual image as hard sample data become available. Indicator geostatistics allow one to interpolate from areas where samples exist to areas where samples are absent. New sampling locations can then be selected so that the uncertainty associated with contamination extent is minimized.

At KAFB RB-11, the soft information available consisted of aerial photos; anecdotal information regarding the number, size, location, and content of each trench; and several non-intrusive geophysical survey results for the site. This information was used to construct a conceptual image of the contamination at the site. Figures 3 and 4 show a plan view and cross-section, respectively, of this conceptual image in which soils are gray-scale coded, ranging from white (highly unlikely that contamination is present) to black (contamination known to exist). Most of the site appears as variations of gray, since relatively little hard sampling data were available at the outset.

The conceptual image served as the basis for both the RCRA sampling program as well as the program designed with Plume™. The sampling strategy for the two investigations was the same: sample as close to trenches as possible without actually penetrating them to determine the likelihood that lateral and/or vertical contaminant migration has taken place. In the case of the RCRA sampling program, soil bore locations were based on a modified grid pattern, with one set of soil bores located west of the trenches, four bores to the east of the trenches and the remainder between the trenches (Figure 3).

Soil bore locations (Figure 3) were selected incrementally with the aid of Plume™ for the Adaptive Sampling program, so that information gain was maximized. Information gain was defined as maximizing the volume of soil in the vicinity of the RB-11 trenches that could be classified as clean at an 80% certainty level. This definition of information gain was equivalent to the stated objective of the RCRA investigation, which was to determine whether contaminant migration had occurred away from the trenches. RCRA



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Figure 3. Plan view of RB-11 conceptual model with the locations for Adaptive Sampling and RCRA soil bores.

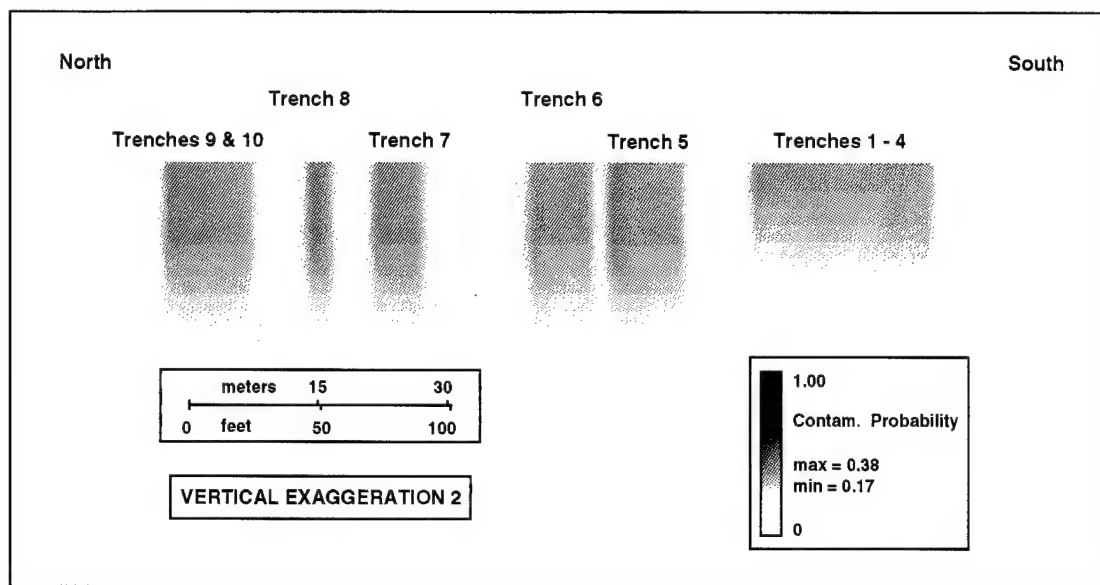


Figure 4. North-South cross-section of RB-11 conceptual model

investigations never completely remove uncertainty regarding the nature and extent of contamination. The level of uncertainty that can be tolerated during a traditional characterization activity has not been specified by the EPA. For the purposes of this comparison, an 80% certainty level was chosen.

The information expected from the RCRA sampling program using the 80% certainty level was evaluated by assuming that the samples would have yielded "clean" results. These samples were used to update the initial conceptual image and measure the volume of soils that would be classified as clean. Locations for the Adaptive Sampling effort were then selected to provide the same information gain, while keeping the number of bores and sampling locations to a minimum. The assumption of clean samples reflects the best possible outcome from the conventional investigation and provides confirmation that contaminant migration has not taken place.

In the first phase of the Adaptive Sampling program, enough soil bore locations were selected to provide the same base amount of information as expected from the conventional investigation. Because of the field analytical methods employed by the Adaptive Sampling program, analytical results for radiation and VOC analyses were available the same day that bores were drilled, while most of the metals analyses were available before the end of the first phase. Based on these results, the conceptual site model was updated using Plume™. If contamination had been encountered, a second phase of sampling would have immediately ensued, with Plume™ providing the locations of new bores. Additional soil bores and sampling would have continued until the contamination extent had been fully characterized.

FIELD PROCEDURES

Background Sampling

Prior to the field demonstration, four subsurface soil samples were obtained for background determination of organic compounds, metals and radiation. The samples were collected using a Geoprobe® at various depths between 5 and 8.5 m (16-28 ft.) from areas known to be uncontaminated near the periphery of the site, approximately 90-120 m (~300-400 ft.) from the ends of the closest trenches (Figure 2). These background samples were analyzed on-site by field screening methods and also in off-site laboratories. The data were used to help formulate a sampling strategy for the demonstration.

A procedure was designed to minimize the amount of material needed for both on-site field screening and off-site analysis. Each soil sample was divided into five splits; three of these were used initially for field screening, and two were sent off-site (Figure 5). In addition, one of the splits used for radiological screening was also sent to an off-site laboratory for isotopic uranium and thorium determinations. This same procedure was followed during the main sampling phase of the investigation in August.

Drilling

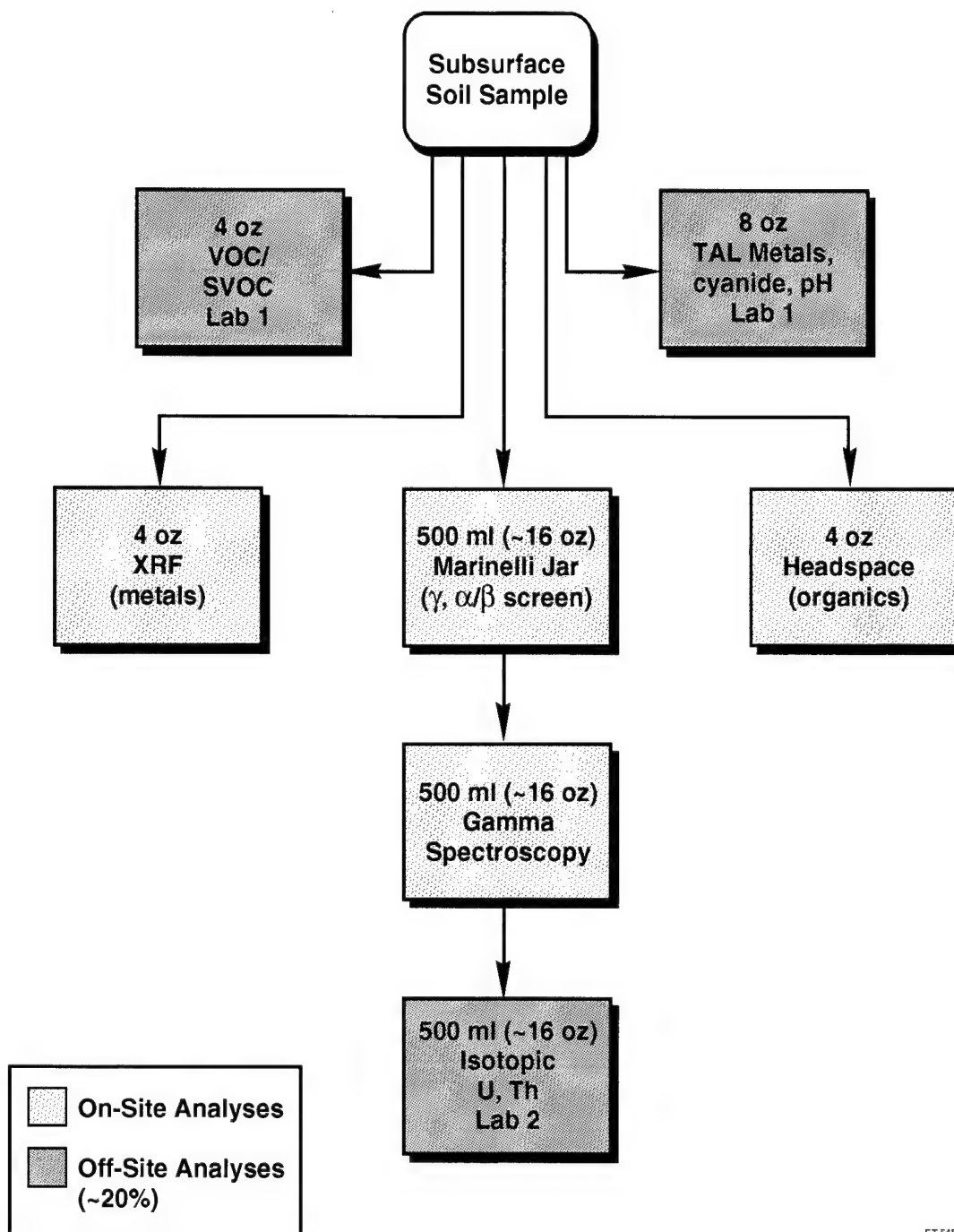
During the August demonstration, 81 soil samples were collected at depth using two Geoprobe® soil samplers which operated simultaneously in the field. The Air Force also used the same two Geoprobess® during their field sampling. Twenty-two of the 28 borehole locations were sampled at approximately 3, 6 and 9 m (10, 20 and 30 ft.) below the surface, while the remaining six holes were sampled at depths of 3 and 6 m (10 and 20 ft). Three additional samples were obtained including two field replicates.

Field Screening Methods

On-site field screening of soil samples for radioactivity and volatile organics was obtained within minutes of bringing the samples to the surface. Similar screening for metals took longer but a substantial number of samples were analyzed prior to the end of the field work.

Field screening instrumentation included a photoionization detector (PID) for headspace analysis of organic vapors; a Geiger-Muller (GM) radiation instrument with an internal sodium iodide detector and pancake probe for gamma radiation; and x-ray fluorescence (XRF) analysis for metals. Soil samples were also scanned for alpha radiation using a scintillometer and beta radiation using a second GM tube. Field screening methods were employed sequentially, with headspace done first to minimize loss of volatile organics. In addition to headspace and gross alpha/beta and gamma detection, a full gamma-ray spectral scan of a split from each sample to be sent off-site was performed within several hours of sample collection.

(Figure 5). Metals analysis by XRF was available within 24 hours. These analyses were done at SNL in a nearby laboratory three miles away, but for the purposes of this study, are considered to have been done "on-site". It should be stressed that the laboratory XRF unit is field transportable and could have been operated at the KAFB RB-11 site within a mobile lab. During background sampling, which preceded the field demonstration, XRF analyses were obtained in one hour. Quick turn-around time for metals was achieved by eliminating a time-consuming grinding step during sample preparation. Previous results using this innovative method have been shown to be reasonably accurate at identifying anomalous samples during field screening (Floran, 1993). Such a rapid analysis strategy ensured quick determination of potential contamination at a particular drilling location.



ET-545-1

Figure 5. Flow diagram illustrating how splits from each subsurface soil sample were allocated for on-site field screening and off-site laboratory analyses.

RESULTS

Field Screening

No elevated values above background readings were obtained. All headspace values were 0 ppm (action levels were set at 10 ppm). XRF results were below RCRA action levels for all metals analyzed. Gamma radiation counts on each soil sample were below background plus two standard deviations, which was the action level used to identify radiological contamination.

Laboratory Analytical Results

Approximately 20% of the total number of soil samples collected were sent to off-site laboratories for confirmatory analyses. These included 15 samples plus two field replicate QA/QC samples. Separate splits of each sample (including background samples) were analyzed for a complete suite of organic compounds, metals and radioactivity. These included 34 volatile organic compounds, 67 semi-volatile species, 23 metals (Target Analyte List [TAL] metals plus mercury), three uranium isotopes, two thorium isotopes, cyanide, and pH. In addition, 73 radionuclide species were analyzed in an on-site laboratory at Sandia by gamma-ray spectroscopy. The tabulated laboratory data may be found in Appendix A.

VOCs, SVOCs

Two volatile organic compounds, methylene chloride and toluene, were detected in a majority of the soil samples; acetone was found in just three samples. All of these occurrences were below human health risk based (HHRB) standards, as defined by the Air Force's RCRA investigation (Halliburton NUS - Draft, 1994). The presence of methylene chloride and acetone are likely to be the result of laboratory contamination. Both compounds were noted in laboratory blanks. In addition, methylene chloride was also found in equipment and trip blanks. Toluene ranged from below detection to 22 $\mu\text{g}/\text{kg}$, well below the HHRB action level of $1.6 \times 10^7 \mu\text{g}/\text{kg}$.

Six semivolatile compounds were detected in the KAFB RB-11 soils, all below action levels. One compound, phenol, was found in every sample and another, bis(2-Ethylhexyl)-phthalate, was detected in most samples. The majority of these occurrences were near or below the reporting limit although in one sample, phenol had a concentration of 1700 $\mu\text{g}/\text{kg}$. The presence of bis(2-Ethylhexyl)phthalate was noted in the equipment blank. Trace quantities of benzoic acid, chrysene and benzo(b)fluoranthene were detected in one sample each, and di-n-octylphthalate was found in two samples, all at levels below reporting limits.

Metals

Only one metal, beryllium, was detected above its action level. All of the samples exceeded this concentration (0.2 mg/kg), ranging from 0.28 to 0.64 mg/kg. These levels of beryllium are typical of the relatively high background values within the area being investigated (Halliburton NUS - Draft, 1994).

Other (Cyanide; Soil pH)

No evidence of hydrogen cyanide or any other metallic salts of hydrocyanic acids were found. Two samples reported cyanide concentrations at or slightly above the reporting limit (0.5, 0.7 mg/kg). The action level for cyanide is 2000 mg/kg. Soil pH ranged from 8.4 to 9.5.

Radiological Compounds

Three isotopes of uranium ($^{233/234}\text{U}$, ^{235}U , ^{238}U) and two isotopes of thorium (^{230}Th , ^{232}Th) were analyzed in an off-site laboratory. Ranges for the uranium isotopes were 0.82-4.8 pCi/g ($^{233/234}\text{U}$), 0.021-0.11 pCi/g (^{235}U), and 0.74-4.4 pCi/g (^{238}U). Thorium isotopes ranged from 0.59-1.4 pCi/g (^{230}Th) and 0.540-1.4 pCi/g (^{232}Th). None of these values are appreciably above background values determined for the site (C. Adams, Capt., USAF, personal communication, 1994).

Radiological contaminants of concern at KAFB RB-11 include the source radioisotopes, ^{90}Sr and ^{137}Cs . ^{90}Sr was not determined. The isotope ^{137}Cs was measured during the field screening phase of the Adaptive Sampling investigation but no values above background were recorded. Analysis of these radioisotopes was not required by the EPA-approved Work Plan, although gross beta determinations provided an indirect indication that neither was present above background levels (Halliburton NUS - Draft, 1994).

Data Transfer Using the Adaptive Sampling Methodology

A SunSPARC workstation at SNL, New Mexico, where the Plume™ geostatistical program resides (four miles from the KAFB RB-11 site), was successfully linked to an identical workstation at Argonne National Laboratory via the Internet. Communication between the workstations was instantaneous. Data from the KAFB RB-11 site were transmitted by FTP to both workstations in minutes using a cellular phone/modem hookup from the field. If contamination had been encountered during the KAFB RB-11 investigation, we planned to use the Plume™ software at Argonne to suggest additional sampling locations. In the near future, it is likely that these types of real-time sampling decisions in the field will be possible from remote locations thousands of miles away.

COST SAVINGS

Substantial cost savings can be obtained by optimizing the number of samples obtained during a site characterization investigation, as well as by judiciously choosing how many of these should be analyzed off-site. The Adaptive Sampling program resulted in drilling 22% fewer boreholes, collecting 50% fewer samples, and analyzing 91% fewer samples in an off-site laboratory. A synergistic cost savings was possible with the Adaptive Sampling approach because fewer samples were collected (compared to the conventional type of investigation) and only a small fraction of the reduced sample set was analyzed. Of these costs, the most significant savings involved laboratory analyses which typically cost greater than \$1K per sample.

For the analyses performed in this investigation, undiscounted prices per soil sample were as follows: VOCs (\$295), SVOCs (\$585), TAL metals plus mercury (\$466), cyanide (\$65), pH (\$25), isotopic thorium (\$178), and isotopic uranium (\$166). However, discounts of up to 50% are typically available to long-term customers. Actual costs for the types of analyses done here might range between \$1K (~50% discount) to \$1.8K (no discount) per sample. Thus, there is a tremendous potential for savings in analytical costs if only 20% of the samples collected are sent to an off-site laboratory, as was done in the present study.

Cost savings achieved by reducing off-site analytical costs must be weighted against additional costs associated with the increased level of effort associated with field screening (labor, depreciation on analytical equipment, report writing, expendables, etc.), as well as the costs associated with the Plume™ software (acquisition, training, personnel required to run the program). In the Adaptive Sampling program, the major additional field screening cost that was not borne by the Air Force investigation was the use of an XRF unit for metals analysis. However, these costs, estimated to be \$30/hr or \$1,600 for the total project (including labor), were minor compared to the savings in off-site analyses. The cost of the SitePlanner/Plume™ software, which is now available for personal computers (PCs), has been steadily dropping. The present costs including training are approximately \$6K.

CONCLUSIONS

The combination of Adaptive Sampling with field screening enabled our project to achieve a similar level of confidence compared to the conventional investigation regarding potential migration of contaminants away from the trenches. By comparison, the Adaptive Sampling project drilled 28 locations vs. 36 for the Air Force, collected 81 samples vs. 163 for the Air Force, and sent 15 samples vs. the Air Force's 163 to an off-site laboratory for analysis. In addition, the Adaptive Sampling field work took 3 1/2 days compared to the 13 days for the Air Force's RFI. These figures translate into large cost savings: 22% fewer boreholes drilled, 50% fewer samples collected, and 91% fewer samples analyzed off-site. Of these costs, the most significant savings involve laboratory analyses which typically cost greater than \$1K per sample for the type of analyses done in the present study.

Despite the large number of samples collectively screened and analyzed in both investigations, no significant contamination above background levels of any kind was found. These results suggest that no gross, systematic migration of contaminants away from the trenches has occurred at the site.

The type of site characterization effort described here, in which geostatistically-based iterative sampling is combined with real-time field screening, is best demonstrated when contamination is present. In such a situation, the value of extensive field screening and avoidance of subsequent sampling phases is more easily quantified. A second phase of demonstration of the Adaptive Sampling methodology at a site with known contamination is scheduled for July 1995.

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APPENDIX A

Table 1A – Summary of Reportable Concentrations for Soil Analysis at RB-11 Site Kirtland AFB, New Mexico.

Chemical Class	Analyte	Back-ground level	S3-10	S3-10 Dup	S5-20	S7-30	S9-20	S11-10	S12-30	S14-20	S16-10	S17-30	S19-20	S21-10	S22-30	S24-20	S24-20 DUP	S26-10	S27-30
VOC	Acetone	12	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.2	1.8	ND
	Benzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Bromodichloromethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Bromoforn	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Bromomethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	2-Butanone (MEK)	4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Carbon disulfide	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Carbon tetrachloride	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Chlorobenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Chloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Chloroform	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Chloromethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Dibromochloromethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	1,1 Dichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	1,2 Dichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	1,1 Dichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	1,2 Dichloroethane (total)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	1,2 Dichloropropane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	cis-1,3-Dichloropropene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	trans-1,3-Dichloropropene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SVOC	Ethylbenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	2-Hexanone	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Methylene chloride	2	2.5	3.2	6.3	3.9	3.2	4.4	4.2	3.4	3.3	3.2	3.2	3.2	ND	1.8	1.6	1.5	1.7
	4-Methyl-2-pentanone (MIBK)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Styrene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	1,1,2,2-Tetrachloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Tetrachloroethene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Toluene	ND	1.5	1.5	1.3	ND	2.6	ND	ND	1.3	7	5.8	2.8	ND	11	2.2	ND	ND	22
	1,1,1-Trichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	1,1,2-Trichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Trichloroethene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Vinyl acetate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Vinyl chloride	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Xylenes (total)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Surrogate	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery
	Toluene-d8	102.6	100	99	99	100	96	100	99	98	100	99	98	104	97	106	105	97	97
	4-Bromofluorobenzene	94.3	97	98	95	99	96	98	100	99	98	99	97	96	96	98	96	97	97
	Phenol	ND	520	510	360	480	290	660	1700	190	130	420	310	160	150	350	190	270	410
	bis(2-Chloroethyl) ether	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	2-Chlorophenol	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	1,3-Dichlorobenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	1,4-Dichlorobenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Benzyl alcohol	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	1,2-Dichlorobenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	2-Methylphenol	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	bis(2-Chloroisopropyl) ether	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	4-Methylphenol	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	N-Nitroso-di-n-propylamine	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Hexachloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Nitrobenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Isophorone	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	2-Nitrophenol	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

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Chemical Class	Analyte	Back-ground level	S3-10	S3-10 Dup	S5-20	S7-30	S9-20	S11-10	S12-30	S14-20	S16-10	S17-30	S19-20	S21-10	S22-30	S24-20	S24-20 DUP	S26-10	S27-30
SVOC	2,4-Dimethylphenol	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Benzoic acid	ND	ND	ND	ND	ND	ND	ND	37	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	bis(2-Chloroethoxy) methane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	2,4-Dichlorophenol	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	1,2,4-Trichlorobenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Naphthalene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	4-Chloroaniline	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Hexachlorobutadiene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	4-Chloro-3-methylphenol	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	2-Methylnaphthalene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Hexachlorocyclopentadiene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	2,4,6-Trichlorophenol	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	2,4,5-Trichlorophenol	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	2-Chloronaphthalene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	2-Nitroaniline	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Dimethyl phthalate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Acenaphthylene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	3-Nitroaniline	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Acenaphthene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	2,4-Dinitrophenol	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	4-Nitrophenol	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Dibenzofuran	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	2,4-Dinitrotoluene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	2,6-Dinitrotoluene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Diethyl phthalate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	4-Chlorophenyl phenyl ether	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Fluorene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	4-Nitroaniline	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	4,6-Dinitro-2-methylphenol	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	N-Nitrosodiphenylamine	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	4-Bromophenyl phenyl ether	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Hexachlorobenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Pentachlorophenol	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Phenanthrene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Anthracene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Carbazole	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Di-n-butyl phthalate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Fluoranthene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Pyrene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Butyl benzyl phthalate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	3,3-Dichlorobenzidine	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Benzol(a)anthracene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	bis(2-Ethylhexyl) phthalate	ND	290	100	58	170	1500	130	380	1200	ND	ND	220	ND	270	520	94	ND	190
	Chrysene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	42
	Di-n-octyl phthalate	ND	ND	53	ND	ND	35	51	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	110
	Benzo(b)fluoranthene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	44
	Benzo(k)fluoranthene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Benzo(a)pyrene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Ideno(1,2,3-cd)pyrene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Dibenz(a,h)anthracene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Surrogate	Benzo(g,h,i)perylene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		Recovery	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery

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SVOC	Nitrobenzene-d5	82.6	75	78	72	80	74	82	82	83	94	82	80	95	86	76	77	96	80
	2-Fluorobiphenyl	87.5	81	83	70	83	83	85	86	88	86	79	82	97	89	80	80	97	89
	Terphenyl-d14	94.6	89	94	86	91	88	94	95	88	93	84	81	100	95	89	99	95	92
	Phenol-d5	80.6	87	88	78	88	77	87	86	82	93	79	82	101	94	84	87	96	88
	2-Fluorophenol	82.3	86	86	78	87	76	85	86	88	97	84	86	105	90	79	85	96	86
METALS	2,4,6-Tribromophenol	83	76	63	67	60	59	72	62	73	71	67	66	72	62	58	63	74	76
	Aluminum	6857.3	8270	4400	6160	4340	4480	3870	11900	5590	6600	4410	5300	7510	4890	3900	6500	7520	6250
	Antimony	3.3	ND	ND	2.4	ND	2.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Arsenic	2.5	3.1	1.6	2.3	1.8	1.7	1.6	3.2	1.7	3.6	1.7	1.5	3.7	3.4	1.6	1.1	3.8	1.4
	Barium	105	163	40.5	106	66.3	45.9	48.1	106	102	133	46.2	68.6	133	44.2	36.4	45.3	74.9	44
	Beryllium	0.55	0.47	0.36	0.4	0.49	0.32	0.28	0.64	0.36	0.54	0.37	0.3	0.48	0.39	0.31	0.3	0.56	0.53
	Cadmium	ND	0.54	0.59	1.3	ND	ND	ND	0.68	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Calcium	36466.6	31400	35600	66800	25100	82400	42200	21200	33000	39300	21700	34400	35900	16600	42200	69700	37000	31900
	Chromium	12.1	13.2	9	9.1	7.3	15.4	7.6	17	12.8	9.9	5.9	34.1	12.2	6.9	23.9	20.8	11.1	15.9
	Cobalt	6	6.5	5.2	4.8	4.7	4.1	4.1	7.3	6	5.5	4.2	5	6.1	3.8	3.8	7.7	6.4	6.6
	Copper	14.1	94.7	51.5	14.8	269	196	157	125	155	112	19.1	138	99.6	46.8	98.8	118	67.6	48.1
	Iron	13225	12400	11000	10900	8370	8950	8800	16500	12500	11900	9100	12200	14700	9350	9660	11400	13900	12600
	Lead	6.5	6.1	4.8	5.5	3.6	4	5	8.5	3.8	6.6	4	3.8	7	3.7	3.6	2	7.9	4.4
	Magnesium	4282.5	5140	3830	3930	3240	4330	3310	5940	4960	5340	3170	4170	5880	2870	3180	8840	6110	5640
	Manganese	311.5	213	249	230	226	226	196	314	239	237	171	223	299	177	185	291	308	352
	Mercury	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.08	ND
	Nickel	170.7	17.3	10.4	8.9	15.3	114	15.4	22.9	62.8	14.1	6.7	100	12.8	16	21.6	23.5	12.2	13.7
	Postassium	1417.5	1570	730	964	853	664	611	1650	735	787	678	776	896	810	619	682	1010	857
	Selenium	0.16	ND	ND	ND	ND	0.84	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Silver	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.3	ND	ND	ND	ND	0.31	ND
RAD	Sodium	316.6	1080	422	584	467	242	81.1	1600	397	479	430	300	494	206	226	403	480	255
	Thallium	0.0021	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Vanadium	23.4	24.8	18.3	19	14	14.8	13	29	23.7	20.5	16.8	23.9	25.8	17.8	17.8	21.9	25.2	25.2
	Zinc	31.7	55.1	37.2	27.4	112	82.7	74.9	93.4	80.5	98.5	25.9	71.4	81.9	32.8	59.9	62.4	67.4	44.4
	Uranium 233/234	0.75	1.1	1.1	1.4	0.93	1.3	0.92	3.5	1.1	1.4	0.85	4.8	0.96	1.3	0.69	1.5	1.4	2
	Uranium 235	0.029	0.034	0.064	0.064	0.033	0.057	0.045	0.32	0.093	0.051	0.036	0.21	0.034	0.04	0.036	0.059	0.065	0.11
	Uranium 238	0.76	1.2	1.1	2.1	0.97	1.3	1	4.4	1.1	1.3	0.82	4.1	1	1.4	0.74	2	1.5	1.8
	Thorium 230	0.75	0.74	0.63	0.7	0.83	0.63	0.76	0.72	0.78	0.77	0.71	1.4	0.81	0.8	0.59	0.84	0.73	0.83
	Thorium 232	0.86	0.54	0.87	0.63	0.88	0.58	0.87	0.51	0.77	0.77	1.2	1.4	0.8	0.8	0.58	0.58	0.6	0.62
	Cyanide	ND	ND	ND	ND	ND	0.5	ND	0.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
OTHER	pH	8.9	8.4	9.3	9.6	9.9	9.5	9.4	8.7	8.4	8.7	8.8	8.7	9	8.8	9.2	8.9	8.8	8.7

Table 1.1A – Summary of VOC and SVOC Background Soil Samples at RB-11 Site Kirtland AFB, NM.

Chemical Class	Analyte	RB-11-1BD	RB-11-3BD	RB-11-4BD
VOC	Acetone	13	12	11
	Benzene	ND	ND	ND
	Bromodichloromethane	ND	ND	ND
	Bromoform	ND	ND	ND
	Bromomethane	ND	ND	ND
	2-Butanone (MEK)	4	ND	ND
	Carbon disulfide	ND	ND	ND
	Carbon tetrachloride	ND	ND	ND
	Chlorobenzene	ND	ND	ND
	Chloroethane	ND	ND	ND
	Chloroform	ND	ND	ND
	Chloromethane	ND	ND	ND
	Dibromochloromethane	ND	ND	ND
	1,1 Dichloroethane	ND	ND	ND
	1,2 Dichloroethane	ND	ND	ND
	1,1 Dichloroethene	ND	ND	ND
	1,2 Dichloroethene total	ND	ND	ND
	1,2 Dichloropropane	ND	ND	ND
	cis-1,3-Dichloropropene	ND	ND	ND
	trans-1,3-Dichloropropene	ND	ND	ND
	Ethylbenzene	ND	ND	ND
	2-Hexanone	ND	ND	ND
	Methylene chloride	2.6	1.2	2.2
	4-Methyl-2-pentanone (MIBK)	ND	ND	ND
	Styrene	ND	ND	ND
	1,1,2,2-Tetrachloroethane	ND	ND	ND
	Tetrachloroethene	ND	ND	ND
	Toluene	ND	ND	ND
	1,1,1-Trichloroethane	ND	ND	ND
	1,1,2-Trichloroethane	ND	ND	ND
	Trichloroethene	ND	ND	ND
	Vinyl acetate	ND	ND	ND
	Vinyl chloride	ND	ND	ND
	Xylenes (total)	ND	ND	ND
	Surrogate	Recovery	Recovery	Recovery
	Toluene-d8	103	101	104
	4-Bromofluorobenzene	92	96	95
SVOC	Phenol	ND	ND	ND
	bis(2-Chloroethyl) ether	ND	ND	ND
	2-Chlorophenol	ND	ND	ND
	1,3-Dichlorobenzene	ND	ND	ND
	1,4-Dichlorobenzene	ND	ND	ND
	Benzyl alcohol	ND	ND	ND
	1,2-Dichlorobenzen	ND	ND	ND
	2-Methylphenol	ND	ND	ND
	bis(2-Chloroisopropyl) ether	ND	ND	ND
	4-Methylphenol	ND	ND	ND
	N-Nitroso-di-n-propylamine	ND	ND	ND
	Hexachloroethane	ND	ND	ND
	Nitrobenzene	ND	ND	ND
	Isophorone	ND	ND	ND
	2-Nitrophenol	ND	ND	ND
	2,4-Dimethylphenol	ND	ND	ND
	Benzoic acid	ND	ND	ND
	bis(2-Chlorethoxy) methane	ND	ND	ND

Table 1.1A – Summary of VOC and SVOC Background Soil Samples at RB-11 Site Kirtland AFB, NM.

Chemical Class	Analyte	RB-11-1BD	RB-11-3BD	RB-11-4BD
SVOC	2,4-Dichlorophenol	ND	ND	ND
	1,2,4-Trichlorobenzene	ND	ND	ND
	Naphthalene	ND	ND	ND
	4-Chloroaniline	ND	ND	ND
	Hexachlorobutadiene	ND	ND	ND
	4-Chloro-3-methylphenol	ND	ND	ND
	2-Methylnaphthalene	ND	ND	ND
	Hexachlorocyclopentadiene	ND	ND	ND
	2,4,6-Trichlorophenol	ND	ND	ND
	2,4,5-Trichlorophenol	ND	ND	ND
	2-Chloronaphthalene	ND	ND	ND
	2-Nitroaniline	ND	ND	ND
	Dimethyl phthalate	ND	ND	ND
	Acenaphthylene	ND	ND	ND
	3-Nitroaniline	ND	ND	ND
	Dimethyl phthalate	ND	ND	ND
	Acenaphthylene	ND	ND	ND
	2,4-Dinitrophenol	ND	ND	ND
	4-Nitrophenol	ND	ND	ND
	Dibenzofuran	ND	ND	ND
	2,4-Dinitrotoluene	ND	ND	ND
	2,6-Dinitrotoluene	ND	ND	ND
	Diethyl phthalate	ND	ND	ND
	4-Chlorophenyl phenyl ether	ND	ND	ND
	Fluorene	ND	ND	ND
	4-Nitroaniline	ND	ND	ND
	4,6-Dinitro-2-methylphenol	ND	ND	ND
	N-Nitrosodiphenylamine	ND	ND	ND
	4-Bromophenyl phenyl ether	ND	ND	ND
	Hexachlorobenzene	ND	ND	ND
	Pentachlorophenol	ND	ND	ND
	Phenanthrene	ND	ND	ND
	Anthracene	ND	ND	ND
	Carbazole	ND	ND	ND
	Di-n-butyl phthalate	ND	ND	ND
	Fluoranthene	ND	ND	ND
	Pyrene	ND	ND	ND
	Butyl benzyl phthalate	ND	ND	ND
	3,3-Dichlorobenzidine	ND	ND	ND
	Benzo(a)anthracene	ND	ND	ND
	bis(2-Ethylhexyl) phthalate	ND	ND	ND
	Chrysene	ND	ND	ND
	Di-in-octyl phthalate	ND	ND	ND
	Benzo(b)fluoranthene	ND	ND	ND
	Benzo(k)fluoranthene	ND	ND	ND
	Benzo(a)pyrene	ND	ND	ND
	Ideno(1,2,3-cd)pyrene	ND	ND	ND
	Dibenz(a,h)anthracene	ND	ND	ND
	Surrogate	Recovery	Recovery	Recovery
	Nitrobenzene-d5	87	73	88
	2-Fluorobiphenyl	86	68	89
	Terphenyl-d14	91	91	102
	Phenol-d5	84	77	81
	2-Fluorophenol	84	78	85
	2,4,6-Tribromophenol	82	84	68

Table 1.1B – Summary of Metals, Radioactive, and Other Background Soil Samples at RB-11 Site Kirtland AFB, NM.

Chemical Class	Analyte	RB-11-1BD	RB-11-2BD	RB-11-3BD	RB-11-4BD
METALS	Aluminum	8500	4940	7430	6560
	Antimony	ND	ND	2.7	4
	Arsenic	3	2	2.1	3.1
	Barium	149	51.1	111	109
	Beryllium	0.89	0.46	0.47	0.4
	Cadmium	ND	ND	ND	ND
	Calcium	23600	31900	6970	53900
	Chromium	12.3	9.4	14.9	12
	Cobalt	6.4	5	6.5	6.3
	Copper	12.3	11.2	15.7	17.3
	Iron	13900	11200	14300	13500
	Lead	8.6	6.1	5.9	5.6
	Magnesium	4120	4050	4660	4300
	Manganese	411	231	340	264
	Mercury	ND	ND	ND	ND
	Nickel	56.5	40.4	105	481
	Postassium	1810	1010	1640	1210
	Selenium	ND	ND	ND	0.16
	Silver	ND	ND	ND	ND
	Sodium	470	ND	248	232
	Thallium	0.0021	ND	ND	ND
	Vanadium	23.3	21.8	26.6	22.1
	Zinc	34.8	25.3	32.6	34.2
RAD	Uranium 233/234	0.76	0.85	0.86	0.53
	Uranium 235	0.046	0.035	0.019	0.018
	Uranium 238	0.75	0.81	0.9	0.59
	Thorium 230	0.97	0.93	0.63	0.47
	Thorium 232	1.1	0.86	0.89	0.59
OTHER	Cyanide	ND	ND	ND	ND
	pH	8.9	9.4	8.2	9.1

Table 1.1C – Summary of Field Screening Gamma-ray Spectroscopy for Background Soil Samples at RB-11 Site Kirtland AFB, NM.

Chemical Class	Analyte	RB-11-2BD	RB-11-3BD
RAD	U-238	ND	ND
	TH-234	ND	ND
	U-234	ND	ND
	RA-226	5.48E-01	4.53E-01
	PB-214	5.80E-01	4.08E-01
	BI-214	5.72E-01	4.73E-01
	PB-210	ND	ND
	TH-232	7.90E-01	6.49E-01
	RA-228	7.90E-01	6.49E-01
	AC-228	7.13E-01	5.85E-01
	TH-228	6.61E-01	5.76E-01
	RA-224	1.55E+00	1.94E+00
	PB-212	6.64E-01	5.78E-01
	BI-212	5.81E-01	3.13E-01
	TL-208	1.99E-01	1.67E-01
	U-235	ND	ND
	TH-231	ND	ND
	PA-231	ND	ND
	AC-227	ND	ND
	TH-227	ND	ND
	AM-241	ND	ND
	NP-237	ND	ND
	PA-233	ND	ND
	TH-229	ND	ND
	AG-110	ND	ND
	BE-7	ND	ND
	BA-133	ND	ND
	BA-140	ND	ND
	BI-207	ND	ND
	CD-109	ND	ND
	CE-139	ND	ND
	CE-144	ND	ND
	CO-56	ND	ND
	CO-57	ND	ND
	CO-58	ND	ND
	CO-60	ND	ND
	CR-51	ND	ND
	CS-134	ND	ND
	CS-137	ND	ND
	CU-64	ND	ND
	EU-152	ND	ND
	EU-154	ND	ND
	EU-155	ND	ND

Table 1.1C – Summary of Field Screening Gamma-ray Spectroscopy for Background Soil Samples at RB-11 Site Kirtland AFB, NM.

Chemical Class	Analyte	RB-11-2BD	RB-11-3BD
RAD	FE-59	ND	ND
	GD-153	ND	ND
	HG-203	ND	Not Significant
	I-125	ND	ND
	I-129	ND	ND
	I-131	ND	ND
	IN-115M	Short Half-Life	ND
	IR-192	ND	ND
	K-40	1.42E+01	1.43E+01
	LA-140	ND	ND
	MN-54	ND	ND
	NA-22	ND	ND
	NA-24	ND	ND
	NB-95	ND	ND
	RU-103	ND	ND
	RU-106	ND	ND
	SB-124	ND	ND
	SB-125	ND	ND
	SB-126	ND	ND
	SC-46	ND	ND
	SN-113	ND	ND
	SR-85	ND	ND
	TA-182	ND	ND
	TL-201	ND	ND
	XE-133	ND	ND
	Y-88	ND	ND
	ZN-65	ND	ND
	ZR-95	ND	ND

Table 2A -- Radiometric Analysis Results.

Chemical Class	Analyte	S3-10	S3-10 Dup	S5-20	S7-30	S9-20	S11-10	S12-30	S14-20	S16-10	S17-30	S19-20	S21-10	S22-30	S24-20	S24-20 DUP	S26-10	S27-30
RAD	Uranium 233/234	1100	1100	1400	930	1300	920	3500	1100	1400	850	4800	960	1300	690	1500	1400	2000
	Uranium 235	34	64	64	33	57	45	320	93	51	36	210	34	40	36	59	65	110
	Uranium 238	1200	1100	2100	970	1300	1000	4400	1100	1300	820	4100	1000	1400	740	2000	1500	1800
	Thorium 230	740	630	700	830	630	760	720	780	770	710	1400	810	800	590	640	730	120
	Thorium 232	540	670	630	880	580	870	510	770	770	1200	1400	800	800	560	580	600	100

Table 2.1A – Radiometric QA/QC Results, 27-Oct-94 and 9-Nov-94.

				Date: 27-Oct-94				Date: 9-Nov-94				
Lab Name: TMA/Eberline				Case No: 4784.100			Case No: 4784.100					
Method Type: RAALP				SDG No.: 9408144			SDG No.: 9408147					
Chemical Class	Control Sample I.D.	Sample Type	Radio-Nuclide	Peak Energy KeV	Measured Value	Known Value	% D	Units	Method No.	Instrument I.D.	Date of Check	
RAD	9408190-01	MB	U223/234	4776	47	0	N.A.	pCi/kg	U-10S	C/11	20-Oct-94	
	9408190-01	MB	U235	4401	7	0	N.A.	pCi/kg	U-10S	C/11	20-Oct-94	
	9408190-01	MB	U238	4196	12	0	N.A.	pCi/kg	U-10S	C/11	20-Oct-94	
	9408190-02	CNTRL	U238	4196	5200	4500	16	pCi/kg	U-10S	C/12	20-Oct-94	
	9408190-03	CNTRL	U238	4196	5000	4500	11	pCi/kg	U-10S	E/2	20-Oct-94	
	9408190-01	MB	Th230	4688	0	0	N.A.	pCi/kg	Th-04S	B/6	21-Oct-94	
	9408190-01	MB	Th232	4010	3	0	N.A.	pCi/kg	Th-04S	B/6	21-Oct-94	
	9408190-02	CNTRL	Th230	4688	2620	2620	4.6	pCi/kg	Th-04S	B/7	21-Oct-94	
	9408190-03	CNTRL	Th230	4688	2620	2620	4.6	pCi/kg	Th-04S	B/8	21-Oct-94	
	9408190-01	MB	U223/234	4776	47	0	N.A.	pCi/kg	U-10S	C/11	20-Oct-94	
	9408190-01	MB	U235	4401	7	0	N.A.	pCi/kg	U-10S	C/11	20-Oct-94	
	9408190-01	MB	U238	4196	12	0	N.A.	pCi/kg	U-10S	C/11	20-Oct-94	
	9408190-02	CNTRL	U238	4196	5200	4500	16	pCi/kg	U-10S	C/12	20-Oct-94	
	9408190-03	CNTRL	U238	4196	5000	4500	11	pCi/kg	U-10S	E/2	20-Oct-94	
	9410169-01	MB	U223/234	4776	55	0	N.A.	pCi/kg	U-10S	C/2	7-Nov-94	
	9410169-01	MB	U235	4401	10	0	N.A.	pCi/kg	U-10S	C/2	7-Nov-94	
	9410169-01	MB	U238	4196	57	0	N.A.	pCi/kg	U-10S	C/2	7-Nov-94	
	9410169-02	CNTRL	U238	4196	5100	4500	13	pCi/kg	U-10S	C/3	7-Nov-94	
	9410169-03	CNTRL	U238	4196	5000	4500	11	pCi/kg	U-10S	E/4	7-Nov-94	
	9408190-01	MB	Th230	4688	0	0	N.A.	pCi/kg	Th-04S	B/6	21-Oct-94	
	9408190-01	MB	Th232	4010	3	0	N.A.	pCi/kg	Th-04S	B/6	21-Oct-94	
	9408190-02	CNTRL	Th230	4688	2500	2620	4.6	pCi/kg	Th-04S	B/7	21-Oct-94	
	9408190-03	CNTRL	Th230	4688	2500	2620	4.6	pCi/kg	Th-04S	B/8	21-Oct-94	
MB=Method Blank												
N.A.=Not Applicable Standard solutions for Lab Control Samples are NIST traceable.												

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